FUTURE U.S. GREENHOUSE GAS EMISSION REDUCTION SCENARIOS CONSISTENT WITH ATMOSPHERIC STABILIZATION

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Abstract

The paper analyzes a scenario for reducing U.S. greenhouse gas (GHG) emissions that is consistent, in the near term, with the President's Global Climate Change Initiative (GCCI) and, in the longer term, atmospheric stabilization at 550 ppm. The purpose for formulating and evaluating such a stabilization scenario is to define the role and expectations for performance of carbon sequestration technologies in a future, speculative carbon-constrained world.

The analysis shows that an integrated approach, involving energy efficiency, cost-effective renewables and availability of advanced CO_2 capture and storage technology, would be required for atmospheric stabilization. Under this scenario, the carbon intensity of U.S. GDP is reduced by 18% in 2012 per the GCCI. From 2012 to 2050, GHG emissions intensity is further reduced toward an absolute target of 1,200 MMmtC/year, representing a substantial U.S. contribution toward a world wide atmospheric stabilization concentration of 550 ppm.

The analysis examines opportunities for reducing emissions (both CO_2 and non-CO_2 GHGs) in all sectors, including transportation, electricity supply, industrial, commercial and residential. It quantifies the potential contribution of the various GHG reduction options and shows that advanced lower-cost CO_2 capture and storage technology will need to play a key role in any future GHG emissions reduction scenario.

Introduction

During the Second Annual Carbon Sequestration Conference, the Department of Energy set forth its initial vision for a "Pathway to Stabilization of CO_2 Emissions" for the U.S.[1] This involved: (1) reducing carbon intensity by 18% by 2012, (2) slowing the growth in GHG emissions past 2012 and stopping this growth in 2025, and (3) then, reversing GHG emissions growth after 2040. The "stabilization of CO_2 (and other GHG) emissions pathway" would make a major contribution, reducing annual CO_2 emissions in year 2050 by nearly 1,500 million metric tons of carbon equivalent (MMmtC/yr), Figure 1A. In this pathway, energy efficiency and renewables, reductions in non-CO_2 GHGs, and particularly the capture and storage of CO_2 were expected to carry the great bulk of the emission reduction burden, Figure 1B. An updated version of the "stabilization of emissions" pathway was included in the Carbon Sequestration Roadmap and Program Plan-2004.[2]

As shown in Table 1, the proposed stabilization of emissions would reduce the carbon intensity of the U.S. economy by more than half. However, in spite of this considerable improvement in the carbon intensity of the U.S. economy, steady economic and population growth would cause total U.S. GHG emission to continue to increase through year 2050.

The Challenge

Responding to the U.S. DOE "Pathway to Stabilization of CO_2 Emissions" scenario, during the Second Carbon Sequestration Conference, David Hawkins of the National Resource Defense Council (NRDC):[3]

- Pointed out that the delays inherent in the DOE/NETL stabilization of CO_2 emissions pathway would pose serious constraints on the economy during the second half of the century, should concentrations of CO_2 in the atmosphere need to be stabilized below 550 ppm. Under this scenario, as shown in Figure 2, the consumption of the bulk of the U.S. carbon budget would require the U.S. to drive the domestic economy toward "zero emissions" after year 2050.

- As such, he challenged the DOE/NETL to consider a more aggressive CO_2 emissions reduction pathway, holding U.S. greenhouse gas (GHG) concentrations below the 550 ppm trajectory set forth in the Wigley, Richels and Edmonds (WRE) scenario.[4]

The Response

In response to this challenge, as well as to better understand the economic impacts of much deeper reductions in GHG emissions, the authors of this paper examined a second pathway for the U.S., one leading to stabilization of atmospheric CO_2 concentrations. The work was prepared with the sponsorship and participation of the DOE/National Energy Technology Laboratory (NETL). The "Pathway to Stabilization of Atmospheric Concentration of CO_2" involves a three part effort:

- Reducing the carbon intensity of the U.S. economy by 18% by the year 2012, consistent with the goals set forth by the President's Global Climate Change Initiative (GCCI).
- Stabilizing annual GHG emissions by year 2025 at or below year 2001 levels of 1.9 Gt of carbon; and
- Reducing annual GHG emissions to 1.2 Gt of carbon by 2050.

Figure 3 presents the annual U.S. GHG emissions by sector, showing that the electric power and transportation sectors are the major sources of GHG emissions both today and potentially in year 2050. Non-CO_2 GHGs, such as methane, nitrous oxide and GWP gases, will be the fastest growing sources of GHG emissions, unless more aggressive mitigation actions are taken than assumed in the Reference Case.

Figure 4 illustrates the magnitude of the challenge, requiring annual reductions in U.S. GHG emissions of nearly 2,200 MMtC in 2050, compared to the Reference Case. To fully appreciate the scope of the challenge, it is useful to recognize that the Reference Case is already a progressively more energy efficient and lower carbon intensity scenario, as shown in Figure 4. As such, recognizing the full scope of the challenge, an emissions reduction strategy aimed at atmospheric stabilization must include all sectors of the economy.

Methodology

Two companies, Advanced Resources and Energetics, Inc., with assistance from the staff of DOE/NETL, joined together for the analysis of the U.S. contribution toward stabilizing atmospheric concentrations of carbon. The work utilizes two models of the U.S. energy economy:

- The Reference Case is primarily based on the U.S. Department of Energy/Energy Information Agency (USDOE/EIA) National Energy Modeling Systems (NEMS), in their analysis of S. 139 and their Annual Energy Outlook (AEO) 2004.[5,6] The authors carry forward the NEMS projections for years 2005-2025 to year 2050, with appropriate adjustments for each of the energy consuming sectors of the U.S. economy.
- The Atmospheric Stabilization Case is based on an updated version of a previously presented carbon sequestration planning model and is called CarBen2.[1] A major step has been to develop a series of sectoral sub-models for: (1) transportation; (2) coal and gas electric power generation; (3) energy intensive industries ; and, (4) renewable energy systems. In addition the authors constructed a long-term model for non-CO2 GHGs that extrapolates forward shorter-term projections from the U.S. Environmental Protection Agency (EPA) for reducing these emissions.[7] The study also incorporated work performed for the U.S. Department of Agriculture on the carbon sequestration potential from forestry and land use changes.[8]

The model draws on cost-supply curves for estimating emission reductions from: (1) forest and land carbon sinks; (2) non-CO_2 GHGs; and, (3) high CO_2 concentration vents. Introduction of "zero emission" hydrogen for transportation and other uses is included as an emission reduction option based on the goals of various U.S. R&D agencies.

Particular emphasis is placed in CarBen2 on CO_2 capture and storage technologies. The model incorporates expectations for significantly lower-cost CO_2 capture technologies. These expectations are based on the goals of the DOE sequestration R&D program and the first phase results from the DOE/NETL, European Union and Klimatek funded and BP led CO_2 Capture Project. The model also includes significant "value-added" uses of the captured CO_2 for enhanced oil, gas and coalbed methane recovery.

Key Assumptions

A series of key guidelines and assumptions are used to guide the CarBen2 model's projections for the atmospheric concentrations stabilization scenario:

1. Efficiency, renewables and reductions in non-CO_2 GHGs are each expected to play a major role.

2. CO_2 capture from high concentration industrial CO_2 vents and storage with EOR/EGR builds the essential CO_2 capture and storage infrastructure.

3. Capital stock turnover retires old, inefficient power plants. Lower cost carbon capture technology is applied aggressively to new power plants built after 2012.

4. Vehicle mileage efficiency improves substantially with new engine technology, efficiency standards and less use of older cars. Production of hydrogen (with CO_2 capture) is increasingly used after 2025 for transportation and other energy applications.

5. Economic incentives, equal to a shadow price of $50 per metric ton of carbon, are used to provide price signals to the market. The $50 per metric ton of carbon ($13.64 per metric of CO_2) shadow price helps ensure that the most cost-efficient (least-cost) mix of emissions reduction options are selected by the model.

6. Finally, efficiency standards are applied, consistent with technology availability, to send market signals to transportation and consumer appliance sectors where reliance on only price signals would be inefficient.

Capital Stock Turnover

An important element for reaching atmospheric stabilization of CO_2 concentrations is the model's expectations for capital stock turnover, particularly in the transportation and electric power sectors. For example:

- Studies show that over 80% of passenger car vehicle miles are traveled in automobiles 5 years or less in age.[9] This supports rapid gains in mileage efficiency and reductions in emissions as new higher efficiency vehicles are introduced and intensively used.

- The model assumes a significant retirement of older domestic electric power plants, given a $50 per ton of carbon shadow price for CO_2 emissions and the introduction of higher efficiency generation technology. Specifically, by 2050: (1) the majority, 296 GW of the 307 GW of coal-fired power plant capacity in current use is retired; and, (2) all of the 64 GW of combined-cycle, base-load natural gas-fired power plant capacity is replaced with more efficient units.

- The steady turnover of capital stock in the electric power industry supports the efficient incorporation of CO_2 capture technology, particularly for plants built after 2012, as shown for coal-fired power plants in Figure 5A and for natural gas-fired power plants in Figure 5B.

- With the expected capital stock turnover in the power sector, the high importance of early commercial availability of low-cost, advanced CO_2 capture technology becomes clear. Incorporating CO2-capture technology into a new power plant is a much more efficient strategy than attempting to retrofit a power plant built without consideration of this option.

Key Study Questions

Because considerable skepticism exists as to whether this more stringent "pathway" is feasible, a series of questions are being addressed by this study of stabilizing atmospheric concentrations of carbon:

- Are such deep reductions in GHG emissions possible without causing a major dislocation in the U.S. economy or energy sector?

- Can these deep reductions be achieved at moderate costs to the domestic economy?, and

- What will need to be the role of carbon sequestration and other GHG emissions control technologies?

Results of the Analysis

The analysis shows that reaching stabilization of atmospheric concentrations of carbon, while a monumental challenge, is feasible. However, the domestic energy production and utilization sectors would need to change radically. The question is, what would the U.S. look like at the end of this pathway, in year 2050?

1. *Significant Improvement in Transportation Efficiencies (Year 2050):*
   - Advanced hybrid engine technology and "stock turnover" provide a composite light-duty vehicle fleet efficiency of 54 mpg.
   - Industry's fuel efficiency goals for heavy duty trucks and aircraft are met by 2025, with further improvements by 2050.
   - Aggressive installation of public transportation and "smart highways" reduces light-duty vehicle miles traveled as well as commercial transportation fuel use by 10%.
   - CAFE standards are initiated and follow commercial availability of advanced, more-fuel-efficient transportation technology.

2. *A Modern Electric Power Generation Sector (Year 2050):*
   - Non-hydro renewables increase by nearly twenty fold, to 850 Bkwh/yr.
   - Coal and natural gas-fired power plants achieve a composite efficiency of nearly 63%; new (post 2025) coal and natural gas plants reach 54% and 67% efficiencies (including CO_2 capture).
   - Hydro and nuclear power remain at about 300 and 800 Bkwh/yr, respectively.

3. *Extensive Use of Carbon Capture and "Value-Added" Geological Storage (Year 2050):*
   - Carbon capture is used by 70% of new coal-fired power plants built between 2012 and 2025 and 90% of new coal-fired power plants built after 2025.
   - Domestic oil production is increased by 2 to 3 million barrels per day from use of captured CO_2 for enhanced oil recovery.

4. *Impressive Reductions in Emissions of Non-CO_2 GHG Gases (Year 2050):*
   - Industrial sources of methane emissions are essentially eliminated.
   - Agriculture practices reduce nitrous oxide emissions and substitutes are developed for high GWP gases.

5. *A Variety of Other Actions Contribute to the Goal (Year 2050):*
   - Forest and land carbon sinks provide 70 MMtC per year.
   - The great majority of high CO_2 concentration industrial vents are captured.
   - Widespread use of "high efficiency appliances" and CHP in the residential, commercial and industrial sectors provide cost-effective CO_2 reduction in all segments of the U.S. economy.
   - Hydrogen begins to make a contribution in transportation and other energy systems.

Figure 6 illustrates the major reductions in carbon emissions required to reach the atmospheric stabilization goal. Table 2 sets forth, in more detail, the portfolio of emission reduction actions that will be required.

- To meet the goal, the greatest reduction in carbon emissions, 700 MMtC, will need to occur in the electric power sector. This challenging set of reductions may be achievable by:

- Increased use of renewables and reduced electricity demand, providing 100 MMtC of reductions.
- Improved efficiencies in power generation, providing 170 MMtC of reductions.
- Capture and sequestration of CO_2 from power generation, providing 430 MMtC of reductions.

- The second greatest reduction in carbon emissions, 420 MMtC, will need to come from non-CO_2 GHGs, particularly methane and the high GWP gases:
  - The non-GHG cost-supply curve, constructed for this study from data assembled by the EPA, shows that significant reductions are possible at a shadow price of $50 per ton, of carbon ($13.64 per metric ton of CO_2) particularly for methane emissions.
  - In addition to price based reductions, substitutes are developed for essentially all of the high GWP gases.
- Third, but following closely behind, are the 410 MMtC of emission reduction requirements from the transportation sector. This sector poses special challenges given the dispersed nature of the emissions and the lack of sensitivity of private vehicle use to significant increases in fuel prices.

Finally, a series of other actions, together providing 630 MMtC of net reductions, are required to reach the atmospheric stabilization target. These include:

- Capture of high CO_2 concentration vents from energy producing industries, such as refineries, gas-processing plants and cement and ammonia manufacturing, providing 110 MMtC.
- Increased storage of CO_2 in terrestrial systems, although soil carbon saturation levels limit this option to 70 MMtC by year 2050.
- A variety of efficiency and demand reduction actions, providing 250 MMtC.
- The remaining 200 MMtC of CO_2 reductions are from the introduction of "zero-emissions" hydrogen, involving CO_2 capture and sequestration.

Conclusions

A technology and policy rich portfolio of initiatives for GHG emission reductions may provide a moderate cost pathway for the U.S. role in the pathway toward atmospheric stabilization of carbon concentrations. Carbon capture and storage will need to play a major role, providing over one-third of the required reductions. Development of lower cost CO_2 capture technology and combining CO_2 storage with EOR/EGR are two important first steps.

Acknowledgements

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Table 1. U.S. GHG Intensity and Emissions 2001-2050

Year	GHG Intensity (tC/MM$GDP)	GHG Emissions (MMtC) CO_2	GHGs
2001	208	1,588	1,921
2012	177	1,880	2,290
2025	151	2,270	2,790
2050	98	2,640	3,360

Table 2. U.S. GHG Emission Reductions Required to Achieve Stabilization of Atmospheric Concentrations of Carbon

	2050 Reference Case	Reduction	2050 Atmospheric Stabilization
Electricity	**980**	**(700)**	**280**
• Increased Renewables/Reduced Demand		(100)	
• Improved Power Plant Efficiency		(170)	
• Power Plant CO2 Sequestration		(430)*	
Transportation	**920**	**(410)**	**510**
Other/Offsets	**740**	**(630)**	**110**
• CO2Vents/Sequestration		(110)*	
• Other/Efficiency / Reduced Demand		(250)	
• Terrestial Offsets		(70)	
• Hydrogen w/CO2 Sequestration		(200)*	
Non-CO2 GHGs	**720**	**(420)**	**300**
	3,360	(2,160)	1,200

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Figure 1. Pathway To Stabilization Of Atmospheric Emissions

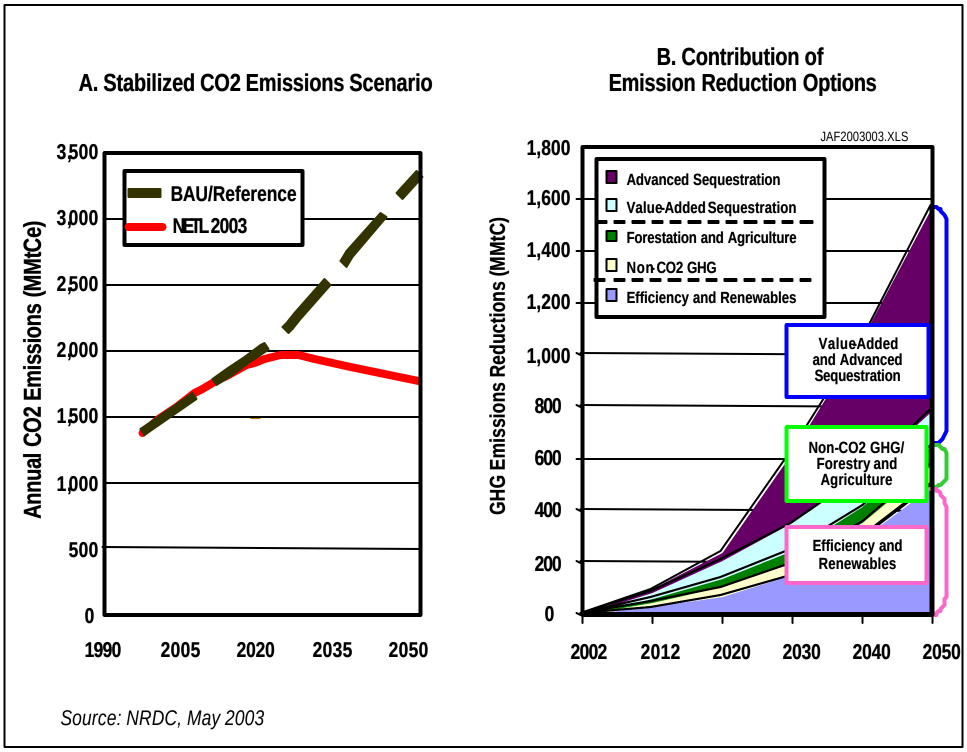


Figure 2. Impact Of Delay On Stabilization Options

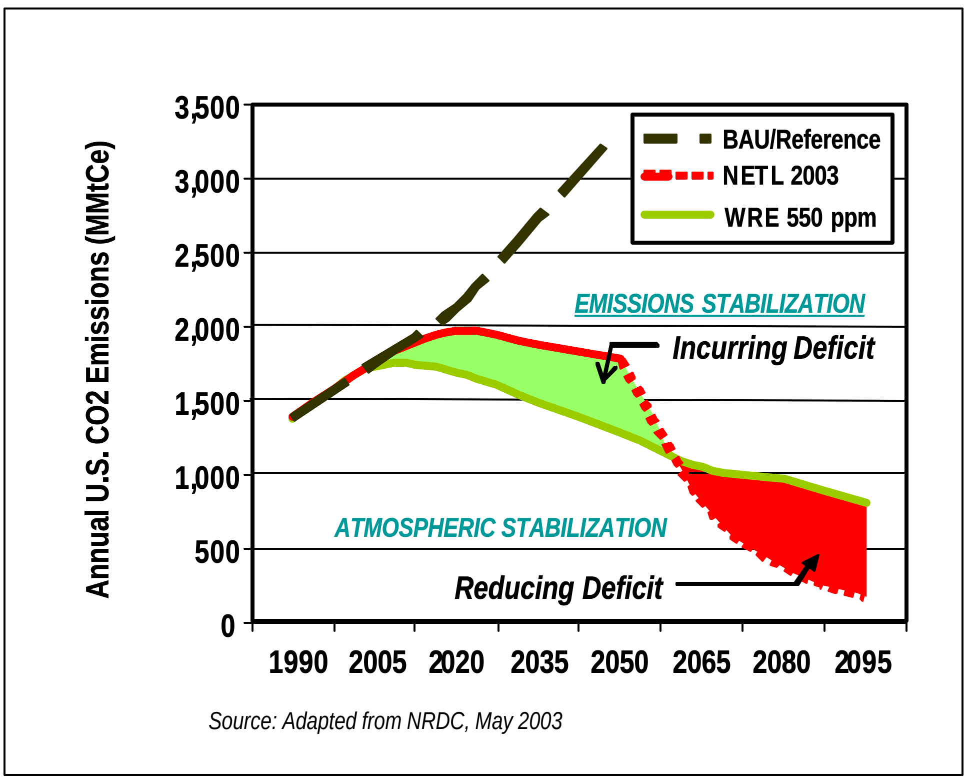


Figure 3. Sources Of GHG Emissions: Today And In 2050

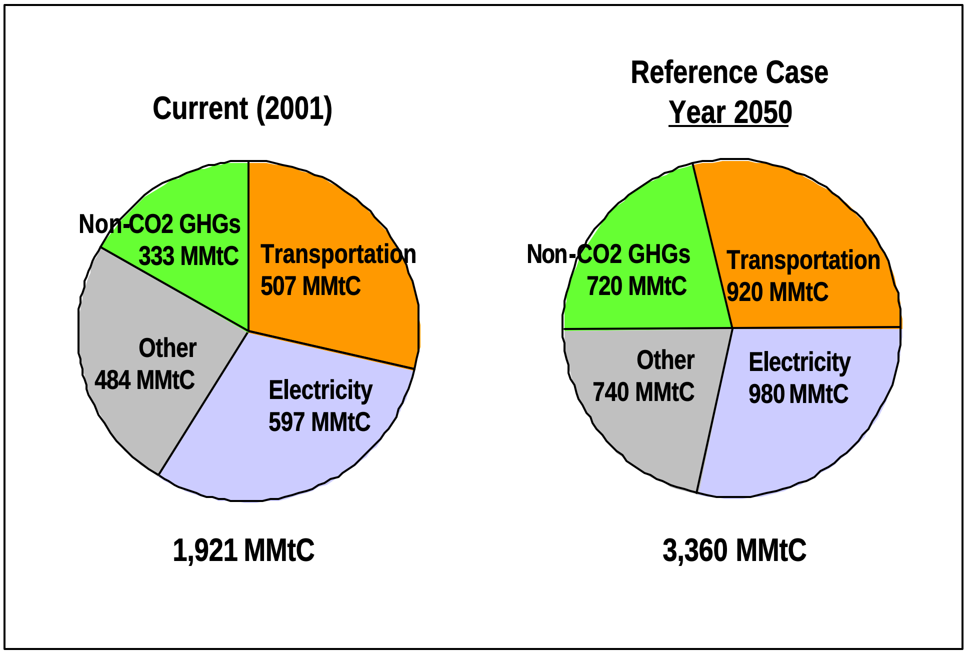
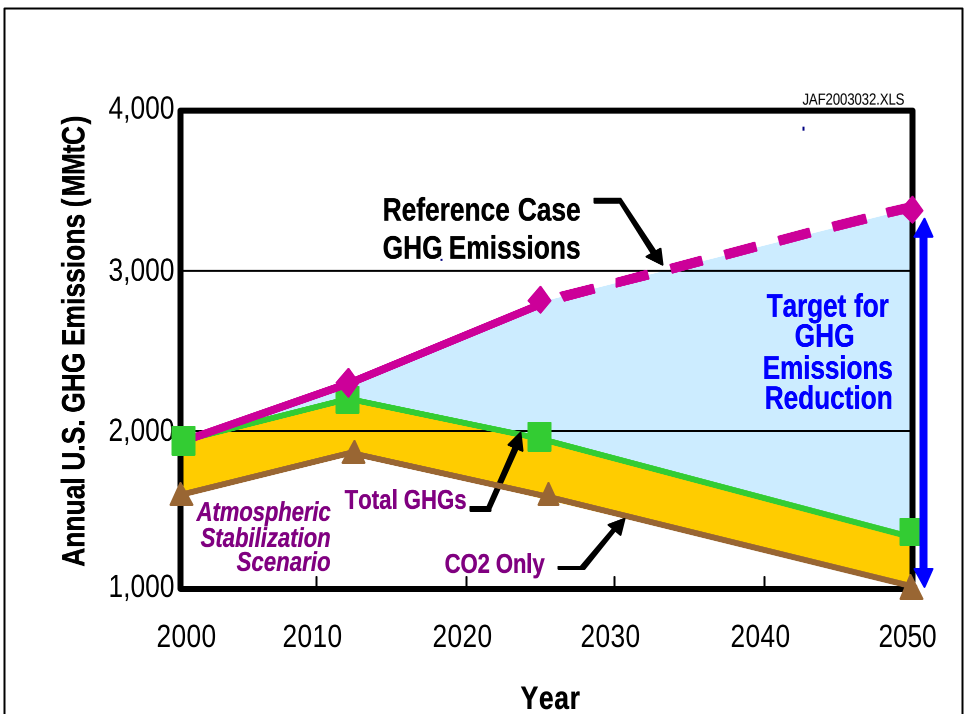


Figure 4. Reference Case And Atmospheric Stabilization, U.S. GHG Emissions



Source: EIA AEO 2004; (Kuuskraa and DiPietro (2004).

Figure 5A.
Projected Capital Stock Turnover in the Electric Power Sector in the Atmospheric Stabilization Scenario

Figure 5B.
Natural Gas-Fired Power Plants

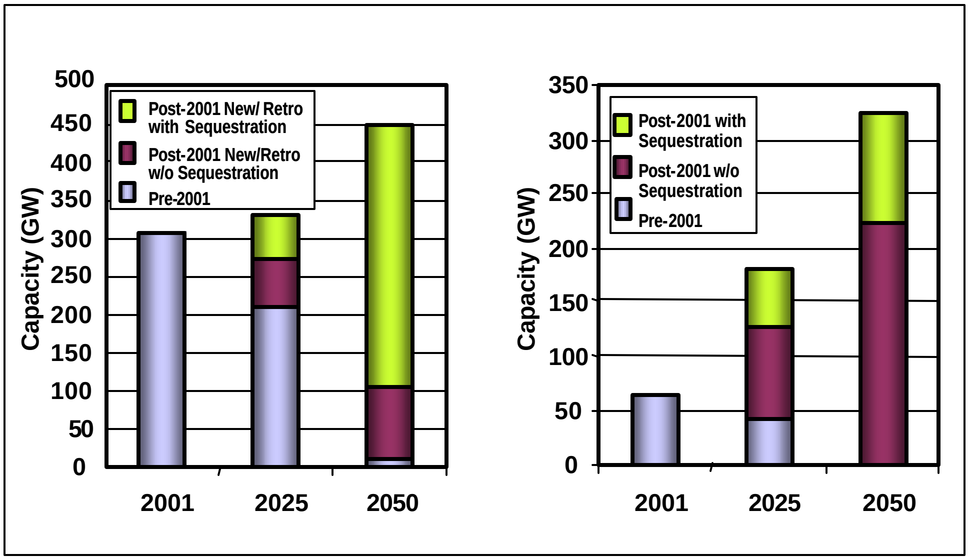


Figure 6. U.S. GHG Emission Reductions Required to Achieve the Stabilization of Atmospheric Concentrations Goals